Patent Application

Automated Regeneration Apparatus and Method for a Particulate Filter

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Attorney's Docket No. 38578-0015US

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[0001] The present invention claims the benefit of priority from co-pending U.S. Provisional Patent Application No. 60/448,836 (Attorney Docket No. 38578-0015P) filed February 18, 2003, fully incorporated herein for all purposes.

Background of the Invention

a) Field of the Invention

[0002] This application is directed particulate filters and more specifically to a method and device for cleaning diesel particulate filters.

b) Description of Related Art

[0003] Diesel engines emit several air pollutants of concern. One of the most significant of these is particulate matter (PM). For PM control, a diesel particulate filter (DPF) is known to be effective at filtering or trapping diesel particulate matter. The physical separation (or filtering) of the PM filter may be determined by filter properties such as composition and configuration, and as such suitable designs have been developed that are quite effective at filtering the particulate from diesel exhaust. Wall-flow filters made of cordierite and silicon carbide are in widespread use. Many other filter media are in various stages of development, such as metal mesh, woven ceramic, and ceramic fiber meshes.

[0004] Although some methods for PM reduction have been developed, the in-situ removal of the PM still gains attention from many companies and research institutions.

"In-situ soot removal" can be defined as removal of soot by non-mechanical means while the system is installed in the exhaust. This removal process is also known as regeneration.

[0005] A number of approaches for DPF regeneration have been considered. These include thermal mechanisms which heat the DPF to the appropriate temperature, and catalytic mechanisms which lower the soot-oxidation temperature. Thermal approaches include burners, microwaves, electric heaters, catalytic and non-catalytic flameless combustion. Catalytic approaches include catalytic coatings (precious and non-precious metals) applied to the DPF, catalytic coating applied to a pre-filter substrate, and fuel-soluble catalysts that are added to the engine's fuel tank and are subsequently mixed with the combustion-formed soot in the engine cylinder.

[0006] Diesel engines can be coupled with electric generators and power conditioning circuits to provide electric power for use in buildings or otherwise. These are commonly called gensets. A specialized use of gensets is to produce electric power for a building during a loss of service (after a regional transformer failure, for example). These are called back-up generators, or BUGs.

[0007] In most facilities, BUGs are 'exercised' periodically to ensure that they will operate when needed. A typical exercise schedule involves starting the engine and allowing it to run without applied load for a period of 15-30 minutes. Each start emits a significant amount of soot, and additional soot is emitted during the period of operation. As previously mentioned, a DPF is well-suited to physically capture or trap the soot, but oxidation of the collected soot is a challenge because the exhaust gas temperature for BUGs without load is typically in the range of 170 to 270 °C. Such temperatures are far

below that required to oxidize soot on a catalyzed filter (350-400 °C) or an uncatalyzed filter (500-600 °C). It is impossible to predict how often the BUG will be used to power the building, and thus run at a load sufficient to create exhaust temperatures high enough to oxidize particulate. In addition, some BUGs are sized to operate at a load that produces an exhaust temperature that is too low to regenerate the filter without an external energy source. An engine may be exercised many times between such high load operation, with each exercise emitting particulate which is caught by the DPF, thus causing a steady increase in backpressure on the engine. Eventually, the exercise regimen will surpass the limit recommended by the engine manufacturer.

[0008] Several techniques have been developed for regenerating a filter on a BUG. In general they can be grouped into two categories: on-line operation where regeneration occurs while the engine is running, and off-line operation where regeneration occurs while the engine is not running (with the filter remaining on the engine).

[0009] Two on-line regeneration techniques for BUGs are now described. First, a load bank such as a collection of resistive elements housed in an enclosure and then attached to the generator, can be used to impose a load on the BUG while it is running, thus increasing the exhaust temperature to levels which will oxidize soot. Load banks can be permanently wired to the BUG so that every time the engine is exercised it will operate under load, or a load bank can be brought to the genset location and connected periodically as part of a maintenance schedule. There are advantages and disadvantages to both uses of load banks.

[0010] The second on-line regeneration technique is to inject fuel into the exhaust stream to be catalytically combusted on an oxidation catalyst which is either upstream of the DPF or coated on the DPF itself. Such systems typically have a minimum exhaust temperature of about 250 °C to allow the catalytic reaction of fuel to occur. Unfortunately, the major drawback is that this minimum temperature cannot be reliably achieved under no load operating conditions for most commercially available generators.

[0011] Flame based burner systems can be used in the "on-line" or "off-line" regeneration mode. The system provides hot gases upstream of the filter, either while the engine is operating or while the engine is not operating. In principle, it is not difficult to operate a burner that is capable of providing a high temperature, high oxygen environment which is favored for the regeneration of a DPF. However, known burner systems can be affected by the particulate matter in the exhaust and may not be sufficiently durable.

[0012] There are many types of systems that can be used for "off-line regeneration". Microwaves can be generated and guided to the filter device, resulting in high temperatures that can promote filter regeneration. This technique, however, still has not become commercially developed. A resistive electrical heater can also be used for off-line regeneration.

C) <u>List of Related Art</u>

[0013] The following patents and documents describe some of the related art:

[0014] Arvind Suresh, Amjad Khan and John H. Johnson, "An Experimental and Modeling Study of Cordierite Traps - Pressure Drop and Permeability of Clean and Particulate Loaded Traps", SAE Paper 2000-01-0476, 2000.

[0015] EP 0151558A by A. Hergart (Unikat AB, Malmo, Sweden)

[0016] Paul Zelenka, Clive Telford, Dave Pye, and Nik Birkby, "Development of a Full-Flow Burner DPF System for Heavy-Duty Diesel Engines", SAE paper 2002-01-2787

[0017] Product literature for ECS Unikat Combifilter Engine Control Systems Europe AB, Unikat Combifilter Diesel Particulate Filters Product Bulletin, 2001.

[0018] U.S. Patent 4,277,442 by A. Hergart (Unikat AB, Malmo, Sweden)

[0019] U.S. Patent 4,381,643, by T.L. Stark (General Motors Corporation, Detroit, MI)

[0020] U.S. Patent 4,549,398 by Oishi et al. (Toyota Jidosha Kogyo Kabushiki Kaisha, Toyota, Japan)

[0021] U.S. Patent 4,562,695 by Rao et al. (Ford, Dearborn, MI)

[0022] U.S. Patent 4,641,496 by Wade (Ford, Dearborn, MI)

[0023] U.S. Patent 4,835,963, by J. Hardy (Allied-Signal, Inc, Los Angeles, CA)

[0024] U.S. Patent 4,902,487 by B.J. Cooper, H.J. Jung and others (Johnson Matthey, Inc., Valley Forge, PA)

[0025] "Microwave-Cleaned Ceramic Filter", by Industrial Ceramic Solutions, Knoxville, TN

Summary of the Invention

[0026] The present invention provides improved systems, devices, and methods for filter regeneration. In particular, some embodiments of the present invention relate to improved techniques for regenerating filters using off-line techniques. In one embodiment, the system provides a control system that invokes a regeneration

sequence for removing contaminants and/or particulates from the DPF. The control system may activate the sequence automatically or based on some indicator. Although not limited in this manner, the regeneration system may be designed for use when the engine is inactive. The regeneration sequence may be initiated after every diesel engine start and stop event, and in one embodiment, may be operated to ensure that every time the engine is started, the DPF will be free of soot. Advantageously, by starting the regeneration immediately after the engine stops, the filter is at an elevated temperature, and subsequently the required electrical input is reduced. The system also optionally includes pressure switches to alert the operator that excessive back pressure levels have been achieved, signaling the desire for system inspection and service. Optionally, a delay before initiation of regeneration might be designed into the system.

[0027] In one embodiment, the present invention comprises of one or more DPFs, tubing to connect the DPF to the engine, means to regenerate the DPF while the engine is not operating, and a control system to start, operate and stop the regeneration means. In the case of multiple DPFs, there may be manifolding and/or valving to connect the DPFs to each other and to the engine exhaust, with the DPFs in a parallel arrangement. In one embodiment, the system is designed with a control system that automatically invokes a regeneration sequence after every start.

[0028] In another embodiment, the present invention comprises of one or more DPFs, tubing to connect the DPF to the engine, a pressure relief valve located upstream of the DPF that directing the exhaust flow away from the DPF and into a sound attenuating

muffler, means to regenerate the DPF while the engine is not operating, and a control system to start, operate and stop the regeneration means.

[0029] In another embodiment, the regeneration means comprises one or more DPFs, one or more electrical heaters installed in modular sections and placed upstream of the DPF(s), one or more air pumps, piping to connect the air pump outlets with the inlet of each electrical heater section, and a control system to start, operate and stop the electrical heaters and air pump.

[0030] In one embodiment, the system comprises of one or more particulate control devices, one or more inlet pipes, one or more outlet pipes, piping to connect the engine and inlet pipe, means to regenerate the filter in place while the engine is not operating (i.e., off-line means), means to determine if the engine is operating, and control means to start the regeneration means after the engine has stopped running. The inlet pipe may be coupled to an inlet of the filter or particulate control device. The outlet pipe may be coupled to an outlet of the filter or particulate control device.

[0031] At least some of these and other objectives described herein will be met by embodiments of the present invention. A further understanding of the nature and advantages of the invention will become apparent by reference to the remaining portions of the specification and drawings.

Brief Description of the Drawings

[0032] Figure 1: Schematic of system. This is with the genset in operation.

[0033] Figure 2: Schematic of system. This is in regeneration mode, with the genset off.

[0034] Figure 3: Schematic of control panel electronics.

[0035] Figure 4: Schematic of system with pressure release valve and actuator.

[0036] Figure 5: Backpressure build-up from repeated cold starts followed by 15 minutes at no load.

[0037] Figure 6: Exhaust temperature for various engine loads.

[0038] Figure 7: Logic diagram for regeneration.

Detailed Description of the Invention

[0039] The present invention provides improved systems, devices, and methods for DPF regeneration. Specifically, the system provides a control system that invokes a regeneration sequence for removing organic particulate matter (soot) from the DPF. The control system may activate the sequence automatically or based on some indicator.

[0040] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed. It is noted that, as used in the specification and the appended claims, the singular forms "a", "an" and "the" include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to "a material" may include mixtures of materials, reference to "a sensor" may include multiple sensors, and the like. References cited herein are hereby incorporated by reference in their entirety, except to the extent that they conflict with teachings explicitly set forth in this specification.

[0041] In this specification and in the claims which follow, reference will be made to a number of terms which shall be defined to have the following meanings: "Optional" or

"optionally" means that the subsequently described circumstance may or may not occur, so that the description includes instances where the circumstance occurs and instances where it does not. For example, if a device optionally contains a feature for system status indicators, this means that the indicator feature may or may not be present, and, thus, the description includes structures wherein a device possesses the indicator feature and structures wherein the indicator feature is not present.

I. Components in the System

[0042] In one embodiment, the present invention comprises an inlet section, means to regenerate the filter while the engine is not operating, a DPF, an outlet section, a control and power panel. The particulate filter can be any of those known in the art, such as wall-flow type filter made of cordierite, or a wall-flow type made of silicon carbide. The DPF may be coated with a catalyst to allow for continuous regeneration of the filter anytime the exhaust temperature is sufficiently high. The filter unit may be attached to the exhaust system and each other by removable and reusable flanges and clamps. In such an embodiment, the modular design also allows for easy service and/or replacement of the DPF or regeneration means.

[0043] Referring now to the embodiment of Figure 1, the regeneration system 10 may comprise a heating element 12, an air pump 14, and piping 16 to connect the air pump with the DPF 18. A relatively small amount of current is required to drive a resistive heating element. A small forced air flow is then used to convect heat from the resistive heater to the filter in a oxidizing atmosphere, thus resulting in combustion of the soot. Electrical regeneration systems may be available from such companies as Engine Control Systems (a division of Lubrizol), and Ibiden.

[0044] As a non-limiting example, the heating element 12 and DPF 18 may be installed in the exhaust flow of the BUG. The heating element 12 can be any of a number of elements in use today. The heater 12 and filter units 18 may be attached to the exhaust system and each other by removable and reusable flanges and clamps (not shown). The control panel 30 contains the devices used to control the regeneration means. The electronics in the control panel 30 may be connected to the generator at the engine operation detector 31. The detector 31 could be the "Switch B+", which is found on most modern generators, is used by other components in the BUG to detect engine operation. Alternatively, the detector 31 could be an engine speed (RPM) sensor, or a flow sensor in the exhaust or intake of the engine. A pressure sensor 19 is attached to the tubing upstream of the exhaust pipe 22. The output of the sensor is directed to the control panel 30 as a means of notifying the operator or engine of overly high backpressure.

[0045] Figure 2 shows a schematic of the system 10 when regeneration is active. During regeneration, the heating element 12 is active, and the air pump 14 is on. Air flow from the pump to the DPF is indicated by arrows 20. Although not limited in this manner, the system 10 is shown to be used while the exhaust flow from the BUG is substantially reduced (or zero), as indicated by the removal of arrows 22 on the exhaust input.

[0046] Referring now to Figure 3, the control panel 30 houses electronics used to start and stop the power supply to the regeneration system 10. In one embodiment, the control panel 30 comprises one or more of a combination of the following: power controllers, step-up voltage transformers, step-down voltage transformers, relays,

timers, delay timers, and power dividers. Surge suppression circuits 41 may also be present to prevent damage to the components during an electrical malfunction, e.g. an electrical short or component overheating. On the front of the panel, there may be switches for the operator as well as indicator devices. As a non-limiting example, the switches may include a main power switch and emergency shut-down switch. The indicators may include, but are not limited to, a current meter for each heater, a status lamp, and a "regeneration-in-progress" indicator lamp. Specifically, the control panel for an electric-heater regenerated system has components shown in Figure 3.

[0047] In the present invention, it may be desirable to determine when the engine is operating. There are many methods for this known in the art, including but not limited to, temperature sensing, oil pressure sensing, measuring the pressure drop across the DPF, and engine speed sensing. In one embodiment, the electronics in the control panel 30 may be connected to the generator at the engine operation detector 31. The detector 31 could be the "Switch B+", which is found on most modern generators, is used by other components in the BUG to detect engine operation. Alternatively the detector 31 could be an engine speed (RPM) sensor, or a flow sensor in the exhaust or intake of the engine. In another embodiment, the control panel 30 may be linked to a signal switch that closes when the BUG is operating. Any of the above or combinations of any of the above, may be used to determine when the engine is operating.

[0048] If a BUG runs for extended periods with the engine's exhaust temperature below the temperature required to regenerate the DPF, the level of the particulate loading will rise, thus increasing the pressure drop through the DPF. In some situations, the pressure drop may increase beyond the manufacturer's recommended level. To

prevent this, a pressure relief valve, or bypass valve, may be included upstream of the DPF. Figure 4 shows such a system. The upstream valve 50 and downstream valve 54 open when the actuators 51 and 55, respectively, are instructed by the control panel 30 to release the valves. Thus, the vast majority of the flow will pass through the muffler 53 since its pressure drop is lower than that of the DPF 18. There are several methods that can be used to determine when the valve should open, including a pressure sensor upstream of the DPF (shown as item 52 in Figure 4). When the engine shuts down, the actuators 51 and 55 will cause the valves 50 and 54 to close. Other means of controlling the valves are clearly possible, including force-based means such as but not limited to weights, levers and hydraulic devices.

II. Operation of the System

[0049] The control panel 30 monitors the system 10 and outputs warnings to the system user. Optionally, the control panel 30 counts the number of starts that the engine has made, including both exercise starts and automatic start when actual backup power is required. The control panel 30 may provide indications (lights, audible alarms) to the engine operators/maintainers optionally through indicators directly on the control panel, or optionally through an interface to the generator control panel. The DPF 18 will therefore be an integral part of the generator system and may be included in the standard maintenance procedures.

[0050] Back-up generators are designed to produce electricity during emergency power outages, and therefore they are 'exercised' periodically to confirm their state of readiness. The frequency of BUG exercise depends on the application, and is normally

weekly, bi-weekly or monthly. In typical tests, the engine is started and allowed to run for ten to thirty minutes without load. These start tests have soot emissions which are captured by the filter, but not burned off because the exhaust temperature is too low (200 to 300 °C). Figure 5 shows the buildup of backpressure during 29 "start and no-load run" tests, in which a cold engine was started and allowed to run for 10 minutes.

[0051] In one embodiment, regeneration will occur through electric regeneration when the engine is off, and by combustion of the particulate matter when the engine runs at a load sufficient to combust the soot. An oxidation catalyst may be coated onto or impregnated into the DPF. This allows the soot to combust at significantly lower temperatures (150-250 °C reduction), and consequently increases the number of engines on which it can be used.

[0052] During occasions when the BUG is the primary source of electricity (during a power failure, for example), the engine is operating under load and the exhaust temperature might be high enough to regenerate a catalyzed filter. Figure 6 shows the effect of engine load on exhaust temperature for a Onan Generator Set Model DFAC 60 Hz, 250 kW, 313 kVA Standby, with LTA10 Cummins diesel engine. The design load of generators is typically between 50% and 80% of the engine rating to ensure long engine life. For example, a 250 kW genset would be used for a 125 kW to 200 kW building load. The data presented in Figure 6 shows that loads of this magnitude result in exhaust temperatures sufficient to regenerate a catalytically coated filter without external energy input.

[0053] Some engines are periodically load tested with a load bank (a device which provides an electrical load to the generator), but it is conceivable that a BUG could

operate without significant load for many years. Therefore, a method of automatic regeneration provides a significant advantage over other methods. In addition, by starting the regeneration immediately after the engine stops, the filter is at an elevated temperature, and subsequently the required electrical input is reduced.

[0054] In one embodiment, the control system 30 may be configured to automatically regenerate the DPF after every start. The regeneration activity or sequence may commence as soon as the engine shuts down, as announced by the closure of switch 43, which is attached to the engine operation detector 31. Returning to the control panel diagram of Figure 3, the sequence of regeneration is described in further detail. Starting in the upper left in Figure 3, there is a switch 40 which activates the power. The power may be AC, but optionally DC. Upon switch closure the two delay timers 42 and 44 are activated. In present embodiment, the delay timer 42 for the heater 12 is shorter than the delay timer 44 of the pump 14 to allow air flow to cool the system after the regeneration is complete. When the delay timers are activated, the air pump relay(s) 46 and heater relay(s) 48 are closed, thus powering the air pump(s) 14 and heating element(s) 12. The air pump 14 may be housed in the control panel, but this is not necessary. In a non-limiting example, the pump 14 is sized to provide about 48 L/hr of air flow per liter of filter. Of course, other flow rates can also be used to facilitate filter regeneration.

[0055] Figure 7 is a logic diagram for the regeneration system 10. The default state of the system is for the engine and regeneration system to be off. The system 10 stays in this state until the engine starts at block 100. If the regeneration system 10 is powered at such a time, it is stopped at block 105 and the delay timer is reset at block 110. Upon

engine shut-off, a change in the engine-operation sensor (e.g., pressure drop through filter, RPM, Switch B+, or the like) will be detected by the control system 30. At this point, the system goes to block 115 and power to the regeneration unit is turned on at block 120. It should be understood that in some embodiments, the regeneration unit may start after the engine drops below a certain RPM, pressure drop, or the like indicating that the engine is about to shut down. When the regeneration is completed (i.e., the required time has elapsed,) after block 140, the regeneration means is turned off at block 145. It should be understood, of course, that besides using time, other indicators such as but not limited to sufficient soot removal, user override, or other selectable indicator may be used to terminate regeneration. if the engine starts during a regeneration, the system 10 jumps to block 100.

[0056] The control panel 30 may be configured to provide indications (lights) to the engine operator through an interface to the generator control panel. Alternatively, the control panel 30 may send signals to the generator control system for inclusion in the generator's diagnostic output.

[0057] While the invention has been described and illustrated with reference to certain particular embodiments thereof, those skilled in the art will appreciate that various optional adaptations, changes, modifications, substitutions, deletions, or additions of procedures and protocols may be made without departing from the spirit and scope of the invention. For example, with any of the above embodiments, the control panel 30 may use software implementations on a chip or processor to control various features such as but not limited to the delay time of devices such as the heater or air pump. As a non-limiting example, the processor may be a single chip electronically coupled to the

air pump and the heating element. The logic of Figure 7 may also be incorporated into a software implementation. The system may be designed to operate not after every engine start, but perhaps at some interval of engine starts. As a non-limiting example, regeneration may occur after every other start, every three starts, every fifth, some combination of the above, or the like. Sensors may be installed in the DPF exhaust system to indicate when regeneration should occur. In another non-limiting example, the regeneration may be sensitive to outside environmental conditions such as weather, humidity, temperature, air pressure, wind, or the like. In some embodiments, the process may be adjusted to account for such variables. The regeneration may also be time sensitive based on time of day, time of the year, season, or the like. The regeneration may be designed to start within about 50, 40, 30, 20, 10, or 5 degrees C of the temperature of the engine exhaust at engine shutoff. The regeneration system may be designed to start after a certain level of soot has been reached in the DPF. In another non-limiting example, the regeneration system may be designed to stop before all of the organic matter has been oxidized, to thus significantly reduce the pressure drop through the DPF, but leave a layer of particulate matter in the DPF to result in maximum particulate control. Thus, the DPF is regenerated up to a point that provides maximum particulate capture. The reason for this is that a perfectly clean DPF might have a particulate capture rate of 60-70%. Over time a layer of particulate builds up in the filter and adds an extra means of particulate capture, and increases the filtering efficiency to 90-99%. In a still further embodiment, the regeneration system may be set to activate when soot levels are reached, even if the engine is active. In one embodiment, a soot sensor may be positioned to determine the level of soot. In other

embodiments, a pressure drop sensor may be used to determine if soot levels are sufficient to activate the regeneration process.

[0058] In some embodiments, the delay time between the air pump and the heating element may also be set or be selectable. The activity of the engine may be monitored by a sensor or the control panel based on, but not limited to, temperature sensing, oil pressure sensing, measuring the pressure drop across the DPF, and engine speed sensing. The heating element 12 may also be configured to use any of the known methods for removing the organic material (soot) from the DPF. With any embodiment of the present invention, microwave devices may be used with the present invention to generate microwaves and guided to the filter device, resulting in high temperatures that can promote filter regeneration. With any embodiment of the present invention, a resistive electrical heater can also be used for off-line regeneration. A relatively small amount of current is required to drive a resistive heating element. A small forced air flow is then used to convect heat from the resistive heater to the filter in a oxidizing atmosphere, thus resulting in combustion of the soot. Electrical regeneration systems are available from such companies as Engine Control Systems (a division of Lubrizol), and Ibiden.

[0059] The publications discussed or cited herein are provided solely for their disclosure prior to the filing date of the present application. Nothing herein is to be construed as an admission that the present invention is not entitled to antedate such publication by virtue of prior invention. Further, the dates of publication provided may be different from the actual publication dates which may need to be independently confirmed. All publications mentioned herein are incorporated herein by reference to

disclose and describe the structures and/or methods in connection with which the publications are cited.

[0060] Where a range of values is provided, it is understood that each intervening value, to the tenth of the unit of the lower limit unless the context clearly dictates otherwise, between the upper and lower limit of that range and any other stated or intervening value in that stated range is encompassed within the invention. The upper and lower limits of these smaller ranges may independently be included in the smaller ranges is also encompassed within the invention, subject to any specifically excluded limit in the stated range. Where the stated range includes one or both of the limits, ranges excluding either both of those included limits are also included in the invention.

[0061] Expected variations or differences in the results are contemplated in accordance with the objects and practices of the present invention. It is intended, therefore, that the invention be defined by the scope of the claims which follow and that such claims be interpreted as broadly as is reasonable.